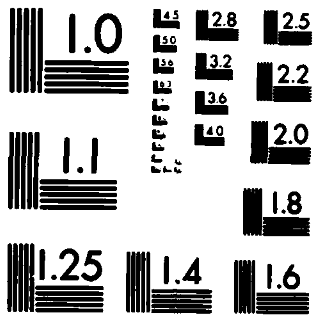
AD-A121 798 COHERENT SCATTERING OF LIGHT INTO HIGH FREQUENCY RADIOWAVES(U) MARYLAND UNIV COLLEGE PARK DEPT OF PHYSICS AND ASTRONOMY J WEBER SEP 82 AFOSR-TR-82-1013 1/1

UNCLASSIFIED AFOSR-77-3399 F/G 20/6 NL

END
DATE
FILMED
84
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

AFOSR-TR- 82-1013

AD A121798

# ANNUAL REPORT

To

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

On

# COHERENT SCATTERING OF LIGHT INTO HIGH FREQUENCY RADIOWAVES

AFOSR 77-3399

September 1982





UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

COHERENT SCATTERING OF LIGHT INTO HIGH FREQUENCY RADIOWAVES

Annual Report on Contract AFOSR 77-3399

To

THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

J. Weber

University of Maryland, College Park, Maryland

and

University of California, Irvine. California

UNCLASSIFIED

SECURITY CLASSIFICATION OF HIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. AD-A121798 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) COHERENT SCATTERING OF LIGHT INTO HIGH FREQUENCY RADIOWAVES | | 5. TYPE OF REPORT & PERIOD COVERED Annual Report 1 Oct 81 - 30 Sep 82 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) J. Weber | | 8. CONTRACT OR GRANT NUMBER(s) AFOSR 77-3399 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics and Astronomy University of Maryland College Park, Maryland 20742 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2305/C1 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research Bolling Air Force Base, Washington, D.C. 20332 | | 12. REPORT DATE September 1982 |
| | | 13. NUMBER OF PAGES 24 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report) Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The coherent interaction of light with an ensemble of nuclear magnetic moments in a crystal is being studied at low temperatures, together with coherent Raman scattering by electrons.

UNCLASSIFIED

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## Summary

During the past year research was performed to improve our theory of coherent scattering of light by large number of particles with strong coupling to each other. Low temperature experiments have been carried out to observe, for the first time, the coherent interaction of light with nuclear magnetic moments. At low temperatures the spin-lattice relaxation time is very long. The cross section was observed to increase slowly with a time scale of hours, corresponding to that spin lattice relaxation time. For this reason it is believed that the strong interaction characteristic of coupled particles was being observed.

Construction of a microwave wide band receiver to measure the cross section for coherent Raman scattering by electrons has required several months, and no new results are available.

# Coherent Radiation Interaction, and Scattering by Atomic Nuclei in a Crystal

J. Weber

University of California, Irvine, California 92717

and

University of Maryland, College Park, Maryland 20742

## ABSTRACT

The coherent radiation interaction, and scattering, by nuclei of a crystal for which each volume element has the same sign of the interaction with an incident beam, and for which the coupling of scatterers with each other is important, is computed.

An experiment is described which appears to verify the theory.

## Introduction

The scattering of x-rays by solids has been well understood for many years. Each volume element of the solid has charges of both signs. Nonetheless the smaller mass of the electrons and the manner in which they are coupled to nuclei and to each other result in a scattering amplitude mainly contributed by the electrons.

The nuclei of a solid may also interact with radiation. Their coupling with each other is readily observed in nuclear magnetic resonance and other experiments. The lattice is a much more rigid structure than the electrons. Sufficiently great rigidity will be shown to lead to much stronger interaction with certain kinds of radiation.

First we will present a general discussion of the interaction of two four current densities. This will be applied to a single scatterer with a number of possible sites.* Exchange of momentum by a single scatterer with several possible sites will be shown to have features which suggest a strong interaction mechanism for N tightly bound particles on N sites.

*Certain stationary states require an atom to be on more than one site. For example the nitrogen atom in ammonia occupies two potential minima, on each side of the plane of the hydrogen atoms, with equal probability.

INTERACTION OF FOUR CURRENT DENSITIES

Let us consider the S matrix for interaction of two four current densities[1] given by

$$S = \frac{1}{\hbar c}\int \langle F|\bar{\psi}_s \Gamma \psi_s \bar{\psi}_I K \psi_I|0\rangle d^4x \tag{1}$$

$\langle F|$ is the final state, $|0\rangle$ is the original state. $\bar{\psi}_s$ is a creation operator for scatterer S, $\bar{\psi}_I$ is a creation operator for incident particle I. $\psi_s$ and $\psi_I$ are the corresponding annihilation operators. $\Gamma$ and K are position independent operators.

The operators $\bar{\psi}_s$ and $\bar{\psi}_I$ are represented by the following expansions[2].

$$\bar{\psi}_s = \sum_n \sum_j \psi^*_{sjn}(\bar{r} - \bar{r}_n)\, a^\dagger_{jn}$$

$$\bar{\psi}_I = \frac{1}{\sqrt{V}} \sum_k \bar{U}_{Ik}\, e^{-\frac{i}{\hbar}\bar{p}_{Ik}\cdot\bar{r}}\, d^\dagger_k \tag{2}$$

In (2) $\bar{r}$ is the position three vector, $a^\dagger_{jn}$ is a creation operator for the state with wavefunction $\psi^*_{sjn}$, n refers to the n$^{th}$ scattering site. $d^\dagger_k$ is a creation operator for an incident particle with known momentum $\bar{p}_{Ik}$. $U_{Ik}$ is an incident particle spinor.

## SINGLE SCATTERER ON N SITES

Suppose further that there are N sites in a solid material. For the states $\psi_{sjn}$ , harmonic oscillator states are selected. Consider the case of a single scatterer.

The single scatterer can be prepared in a harmonic oscillator ground state with equal probability to be on any one of the N sites. The original scatterer state for the single scatterer is taken to be

$$\frac{1}{\sqrt{N}} \sum_{n=1}^{n=N} a^{\dagger}_{on} \left| \begin{matrix} \text{VACUUM} \\ \text{STATE} \end{matrix} \right\rangle \tag{3}$$

Let us assume that the scatterer position probability distribution $\psi^{*}_{sjn} \psi_{sjn}$ is not changed by the scattering. Therefore the effect of the scattering can only be a phase shift such that each final scatterer state $(\psi_{sjn})_F$ is related to the original state $(\psi_{sjn})_o$ by

$$(\psi_{sjn})_F = (\psi_{sjn})_o \, e^{i p_r x^r / \hbar} \tag{4}$$

(4) implies that each component in the momentum decomposition of the scatterer is shifted by the three momentum $\Delta \bar{p}$ , corresponding to momentum exchange $\Delta \bar{p}$.

For a harmonic oscillator wavefunction centered at radius vector $\bar{r}_n$,

$$\psi_{sjn} = \left(\frac{\alpha}{\pi}\right)^{3/2} e^{-\alpha^2 |\bar{r} - \bar{r}_n|^2} \tag{5}$$

In (5) $\alpha$ specifies the volume occupied by the particle.

We assume spin zero scatterers, $\Gamma = 1$, (1),(2),(3), and (4) give

$$S = \frac{\bar{U}_{IF} K U_{IO}}{\hbar c V N} \int \left(\frac{\alpha}{\pi}\right)^{3/2} \sum_{n=1}^{n=N} e^{-\alpha |\bar{r} - \bar{r}_n|^2 + \frac{i}{\hbar}(p_{Io} - p_{IF} - \Delta p)_\mu x^\mu} d^4x \tag{6}$$

In (6) $p_{Io}$ and $p_{IF}$ are the original and final 4 momenta of the incident particle, respectively. As $\alpha \to \infty$ (6) becomes

$$S \to \frac{\bar{U}_{IF} K U_{IO}}{\hbar V N} \sum_{n=1}^{n=N} e^{\frac{i}{\hbar}(\bar{p}_{Io} - \bar{p}_{IF} - \Delta\bar{p}) \cdot \bar{r}_n} \int e^{\frac{i}{\hbar}(\epsilon_{Io} - \epsilon_{IF} - \Delta E)t} dt \tag{6A}$$

(6) indicates the possibility of exchanging the entire momentum $\Delta\bar{p}$ at any of the possible N sites at which the single scatterer may be found.

For momentum conservation, the sum in (6) approaches N. The possibilities for exchange of energy and momentum do not appear to severely restruct the solid angle into which an incident particle would be scattered.

## COLLECTIVE MOMENTUM TRANSFER PHASE SHIFT INTERACTIONS

Suppose now that we have N tightly bound scatterers. If an incident particle interacts with one scatterer, its strong coupling with all other nuclei might be expected to affect the interaction with an incident particle in a profound way. Consider (6). As already noted, the entire momentum $\Delta\bar{p}$ can be exchanged at any site without possibility of identifying the site of the scattering. With sufficiently strongly coupled particles momentum transfer at a single site is immediately exchanged with all other particles, with no possibility of identifying the site at which the scattering occurred.

For N tightly bound scatterers the original state is selected as

$$a^{\dagger}_{01} a^{\dagger}_{02} a^{\dagger}_{03} \cdots a^{\dagger}_{0N} \left| \begin{matrix} \text{VACUUM} \\ \text{STATE} \end{matrix} \right\rangle \tag{7}$$

For nuclei in a solid, the wavefunctions of different scatterers will not overlap to a significant degree, and the symmetry of the wavefunction need not be considered.

For exchange of momentum $\Delta p_\mu$ at the $j^{th}$ site, $\overline{\psi}_s$ in (2) must be replaced by

$$\overline{\psi}_s' = \psi^*_{soj} a^{\dagger}_{oj} e^{-\frac{i \Delta p_\mu x^\mu}{\hbar}} + \sum_{i \neq j} \psi^*_{soi} a^{\dagger}_{oi} \tag{8}$$

We may write (8) in a more illuminating form by adding $\psi^*_{soj} a^{\dagger}_{oj}$ to the last term and subtracting it from the first term to give

$$\overline{\psi}_s' = \psi^*_{soj} a^{\dagger}_{oj} \left[ e^{-\frac{i \Delta p_\mu x^\mu}{\hbar}} - 1 \right] + \sum_{\text{ALL } N} \psi^*_{soi} a^{\dagger}_{oi} \tag{8A}$$

In (8A) the last term is the probability amplitude for the possible process where no momentum is exchanged at any site. The first term then gives the contribution to the amplitude for exchange $\Delta p_\mu$ at the $j^{th}$ site. Since we are assuming strong coupling of nuclei to each other with no possibility of identifying the scattering site we must sum only the first term in (8A) over all possible sites.

This gives, for collective momentum transfer phase shift scattering

$$S = \frac{\bar{U}_{IF} K U_{IO}}{\hbar c V} \int \sum_{n=1}^{n=N} \left(\frac{\alpha}{\pi}\right)^{3/2} e^{-\alpha|\bar{r}-\bar{r}_n|^2 + \frac{i}{\hbar}(p_{IO}-p_{IF}-\Delta p)_\mu x^\mu} d^4x \qquad (9)$$

## SCATTERING CROSS SECTIONS

Suppose now that we have nuclei in a cubic crystal with N identical cells each with length a. For these assumptions the S matrix (9) for initial and final states in which the harmonic oscillator quantum numbers are the same, is given by

$$S = \bar{U}_{IF} K U_{IO} X Y Z T \left(\frac{1}{\hbar V}\right) \qquad (10)$$

with

$$X = \sum_{n=1}^{n=N^{1/3}} e^{\frac{i}{\hbar}(p_{IO}-p_{IF}-\Delta p)_x X_n - \frac{1}{\alpha}\left(\frac{p_{IO}-p_{IF}-\Delta p}{2\hbar}\right)_x^2}$$

In (10), $X_n = n a$, with corresponding definitions for Y and Z. As before, $\alpha$ is a parameter specifying the width of the harmonic oscillator wavefunction.

$$T = \frac{\sin\left[\frac{(E_{IF}-E_{IO}+E_{SF}-E_{SO})\tau}{2\hbar}\right]}{\left[\frac{E_{IF}-E_{IO}+E_{SF}-E_{SO}}{2\hbar}\right]} \qquad (11)$$

$E_{IF}$ and $E_{SF}$ are the final state energies of the incident particle and ensemble of scatterers respectively, $E_{IO}$ and $E_{SO}$ are the corresponding original energies.

The scattering cross section is given by $\sigma$, with

$$\sigma = \sum \frac{V(S-1)^2}{c\tau} = \frac{V}{(2\pi)^6 c\tau\hbar^8} \int \left| \bar{U}_{IF} K U_{Io} XYZT \right|^2 dp_s \, dp_I \tag{12}$$

In (12) $d\bar{p}_S$ is the element of momentum space for the final state of the ensemble of scatterers, $d\bar{p}_I$ is the element of momentum space for the final state of the incident particle. T in (11) and (12) is a function of the momentum variables in X, Y, and Z. The integration (12) is carried out in the following way:

The length L of the crystal is given by $L = aN^{1/3}$, to a very good approximation we may evaluate

$$\frac{L}{2\pi\hbar} \int X^2 dp_{Sx} = \frac{L}{2\pi\hbar} \int \left[ \frac{\sin\left(\frac{N^{1/3} a \left[p_{Io} - p_{IF} - \Delta p\right]_x}{2\hbar}\right)}{\sin\left(\frac{a\left[p_{Io} - p_{IF} - \Delta p\right]_x}{2\hbar}\right)} \right]^2 e^{-\frac{2}{\alpha}\left(\frac{p_{Io} - p_{IF} - \Delta p}{2\hbar}\right)^2} dp_{Sx} = N^{2/3} \tag{13}$$

Combining (13), (12) and (11) then gives

$$\sigma = \frac{N^2 (\bar{U}_{IF} K U_{Io})^2}{(2\pi)^3 c\hbar^5 \tau} \int T^2 d\bar{p}_I = \frac{N^2 (\bar{U}_{IF} K U_{Io})^2}{(2\pi)^3 c\hbar^5 \tau} \int (T p_I)^2 \frac{d|p_I|}{dE} \, dE \, d\Omega_I \tag{14}$$

with $E = E_I + E_S$, $d\Omega_I$ is the element of solid angle into which the incident particle is scattered.

In the center of mass system

$$\frac{d|p_I|}{dE} = \frac{E_{IF} E_{SF}}{c^2 p_I (E_{IF} + E_{SF})} \tag{15}$$

(14) is integrated over E first

$$\sigma = \frac{N^2\left(\bar{U}_{If} K U_{Io}\right)^2}{4\pi^2 c^3 \hbar^4}\int P_I \frac{E_{If}E_{Sf}}{\left(E_{If}+E_{Sf}\right)}\, d\Omega_I \tag{16}$$

(13) implies that

$$d\Omega_I \sim \left[\Delta p + \frac{2\hbar\pi}{N^{1/3}a}\right]\frac{1}{(P_{Io})^2}$$

The integral (16) is over all values of $\Omega$ which approximately conserve energy and momentum as implied by the integrations (13) and (14). Detailed analyses have shown for the case of zero rest mass particles, that a large volume of phase space meets these criteria. (16) may approach $N^2$ times the cross section of a single particle on one site.

The result (16) was obtained for the very simple cubic model. A similar result may be obtained for any very tightly bound group of scatterers even if these are not arranged in a perfect periodic lattice. For the more general case we may define

$$f\left(\bar{p}_{If}-\bar{p}_{Io}-\Delta\bar{p}\right) = \int e^{\frac{i}{\hbar}\left(\bar{p}_{If}-\bar{p}_{Io}-\Delta\bar{p}\right)\cdot r'}\,\psi^*_{So}(r')\,\psi_{So}(r')\,d\bar{r}' \tag{17}$$

$$R = f\left(\bar{p}_{If}-\bar{p}_{Io}-\Delta\bar{p}\right)\sum_{n=1}^{n=N} e^{\frac{i}{\hbar}\left(\bar{p}_{If}-\bar{p}_{Io}-\Delta\bar{p}\right)\cdot\bar{r}_n} \tag{18}$$

In terms of (17) and (18) the S matrix is

$$S = \frac{\bar{U}_{If} K U_{Io} R T}{\hbar V} \tag{19}$$

$R$ may be evaluated in the following way. In (18) consider the sum

$$\sum_{n=1}^{n=N} e^{\frac{i}{\hbar}(\bar{p}_{IF}-\bar{p}_{I0}-\Delta\bar{p})\cdot\bar{r}_n} \tag{20}$$

and express it as the product of factors involving $X_n$, $Y_n$, $Z_n$

$$\sum_{n=1}^{n=N_x} e^{\frac{i}{\hbar}(\bar{p}_{IF}-\bar{p}_{I0}-\Delta\bar{p})X_n} \sum_{n=1}^{n=N_y} e^{\frac{i}{\hbar}(p_{IF}-p_{I0}-\Delta p)_Y Y_n} \sum_{n=1}^{n=N_z} e^{\frac{i}{\hbar}(p_{IF}-p_{I0}-\Delta p)_Z Z_n} \tag{21}$$

the object

$$X' = \sum_{n=1}^{n=N_x} e^{\frac{i}{\hbar}(p_{IF}-p_{I0}-\Delta p)_x X_n} \tag{22}$$

is the sum of $N_x$ unit vectors. The last one in the sum makes an angle

$$\theta_{N_x} = \frac{i}{\hbar}(p_{IF}-p_{I0}-\Delta p)_x X_N \tag{23}$$

with the first. The increments in angle are not equal, however the sum is given approximately by

$$X' = N_x \frac{\sin\frac{\theta_{Nx}}{2}}{\frac{\theta_{Nx}}{2}} . \tag{24}$$

Similar expressions result for $Y'$ and $Z'$, and

$$R = X'Y'Z' f(p_{IF}-p_{I0}-\Delta p) \tag{25}$$

The phase space integrals then give a result similar to (16).

## DISCUSSION

The large cross sections (16) result from three very important assumptions. The ensemble of scatterers is assumed to be infinitely stiff, and recoils in the same manner as a single elementary particle on the N sites. Expression (8) then states that a final ensemble state differs from an initial state only in the phase factor $e^{\frac{i\Delta p_\mu x^\mu}{\hbar}}$. This phase factor is crucial for obtaining a large cross section because it may enormously increase the solid angle into which scattering occurs.

Suppose first that the phase factor $e^{\frac{i\Delta p_\mu x^\mu}{\hbar}}$ is absent -- as in the published solutions for potential scattering -- in which energy but not momentum is conserved. The absence of $\Delta p_\mu$ may enormously decrease the value of (16), because under this condition (13) implies (center of mass system),

$$\frac{N^{1/3}a\,(p_{Io}-p_{IF})}{2\hbar} << \pi \qquad (26)$$

(26) then limits the solid angle into which scattering may occur, expression (16), to

$$\Delta\Omega < \left(\frac{2\hbar\pi}{N^{1/3}a}\right)\frac{1}{p_{Io}^2} = \left[\frac{2\pi(\text{DE BROGLIE WAVELENGTH OF INCIDENT PARTICLE})}{\text{LENGTH OF SCATTERER ARRAY}}\right]^2 \qquad (27)$$

The limitation of the $\Omega$ integration by (27) results in an extremely small cross section. This limit disappears when the phase factor $e^{\frac{i \Delta p_\mu x^\mu}{\hbar}}$ is included, for $\Delta p_\mu$ the same value for all scatterers.

This follows from the modification of (27) as a result of the collective momentum transfer phase shift, to

$$\Delta\Omega < \quad \Delta p + \frac{2\hbar\pi}{N^{1/3} a \quad (p_{I0})^2} \tag{28}$$

For large N, if $\Delta p \rightarrow p_{I0}$, (28) is enormously greater than (27). The cross section (16) and transition probabilities are correspondingly increased.

The second assumption is that the ensemble consists of highly localized particles which do not, therefore, have well defined momenta. In the appendix it is shown that if the momenta of all scatterers are precisely known before and after the interaction with the incident beam, the total cross section (and transition probability) will be very small.

The third assumption is that the sign of the interaction is the same in all volume elements. For electromagnetic radiation incident on a solid this requires an applied nearly uniform field to obtain essentially the same polarization in all volume elements. For the neutrino field, the universal Fermi interaction has the same sign for all particles of the solid.

## INTERACTION OF PHOTONS WITH AN ENSEMBLE OF NUCLEAR MOMENTS

Several experiments are being carried out to verify this theory. One involves light which is incident on a nearly perfect crystal which is very nearly transparent. Interaction is with the nuclear moments. The nuclei are tightly coupled to each other. An applied constant magnetic field $H_0$ gives a net magnetic polarization. The magnetic moment $\mu$ is given by

$$\mu = g\mu_0 \hbar I \tag{29}$$

In (29) g is the gyromagnetic ratio, I is the spin vector in units of , is the nuclear magneton given in terms of the nuclear mass M electron charge e and speed of light c, by

$$\mu_0 = \frac{e}{2M_n c} \tag{30}$$

The Maxwell vector potential operator is given, in Coulomb gauge by

$$A_i \doteq \sqrt{\frac{8\pi\hbar c}{V}} \sum \frac{1}{\sqrt{2k}} \sum_{m=1}^{m=3} \left( a_m(k) \epsilon_i^m e^{ik_\mu x^\mu} + a_m^\dagger(k) \epsilon_i^m e^{-ik_\mu x^\mu} \right) \tag{31}$$

In (32), $a_m^\dagger(k)$ and $a_m(k)$ are creation and annihilation operators, respectively, for photons. $\epsilon_i^m$ are a pair of orthonormal unit vectors, in a plane perpendicular to $\bar{k}$

For interaction of electromagnetic radiation with nuclear moments the S matrix is given by

$$S = \frac{g\mu_0}{c} \int \langle F | \psi_s^\dagger \psi_s \epsilon^{abc} I_a \frac{\partial A_b}{\partial x^c} | 0 \rangle d^4x \tag{32}$$

In (32) $\epsilon^{abc}$ is the three space Levi Civita tensor density. It is zero if two indices are equal and unity if all indices are different. $\epsilon^{123} = +1$ and changes sign on the interchange of any pair of indices.

For N scatterers in harmonic oscillator ground states (32) is evaluated as

$$S = g r_0 \sqrt{\frac{4\pi\hbar k}{cV}} \int \sum_{n=1}^{n=N} \left(\frac{\alpha}{\pi}\right)^{3/2} e^{-\alpha|\bar{r}-\bar{r}_n|^2 + \frac{i}{\hbar}(p_{x_0}-\Delta p)_\mu x^\mu} \langle F|\eta\cdot I|0\rangle \, d^4x \tag{33}$$

In (33) $\bar{\eta}$ is an appropriate unit vector defined by (32). (33) may be written in terms of the integrals X, Y, Z, T defined earlier with (10), as

$$S = g r_0 \sqrt{\frac{4\pi\hbar c k}{V}} \, X Y Z T \langle F|\eta\cdot I|0\rangle \tag{34}$$

Following the procedures of (12), (13) and (14), the cross section for absorption, or emission, is computed to be

$$\sigma = 4\pi \rho_0^2 k g^2 \hbar N_\mu^2 \tau^{-1} |\langle F|\eta\cdot I|0\rangle|^2 \int T^2 \rho(E)\, dE \tag{35}$$

$$= 8\pi^2 k \rho_0^2 g^2 \hbar^2 \rho(E) \, |\langle F|\eta\cdot I|0\rangle|^2 N_\mu^2$$

$N_\mu$ is the difference between the number of spins parallel and antiparallel to the polarization field.

## Experiments

Red light from a helium neon laser was employed with the apparatus of Figure 1. A crystal of Lithium Fluoride was employed, approximately 2 cms in diameter and 0.5 cms thick. A 9000 Gauss magnetic field was applied and the crystal cooled to 4.2 Kelvin by filling the Dewar with liquid helium. The intensity of the light as measured by the silicon "solar cell" oscillated as shown in Figures 2 and 3, with monotonically increasing period, finally reaching a stationary value usually less than ten percent of the initial intensity, the largest period was approximately equal to the nuclear spin lattice relaxation time. Different values of magnetic field were employed. No evidence for a resonance was observed. These data are consistent with the hypothesis that coherent interaction of light with nuclear moments is being observed. If the coupling between nuclei is not taken into account (27) suggests a total cross section $\approx 10^{-8}$ cm$^2$ which is orders smaller than what is being observed. No quantitative agreement of theory and observations can be made until the dynamic diamagnetism effects are calculated. Many analyses have been made of the internal electric fields as a consequence of shielding effects, and the diamagnetism associated with steady fields is well known. A careful analysis of the diamagnetism at optical frequencies is required in order to predict accurately how much of the incident light is being absorbed. This issue and plans for new observations are being explored.

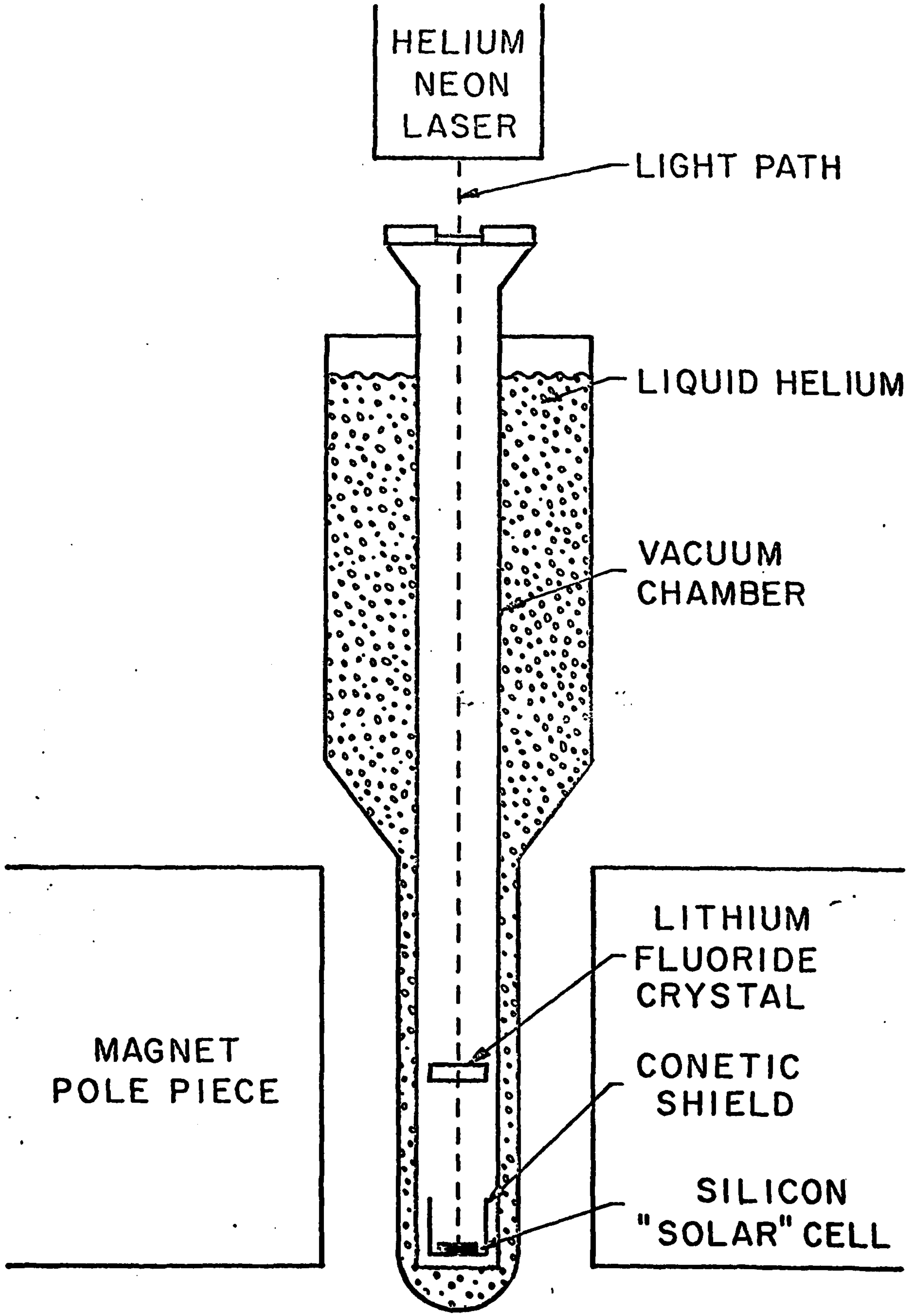

HELIUM
NEON
LASER
LIGHT PATH
LIQUID HELIUM
VACUUM
CHAMBER
LITHIUM
FLUORIDE
CRYSTAL
MAGNET
POLE PIECE
CONETIC
SHIELD
SILICON
"SOLAR" CELL

FIGURE 1

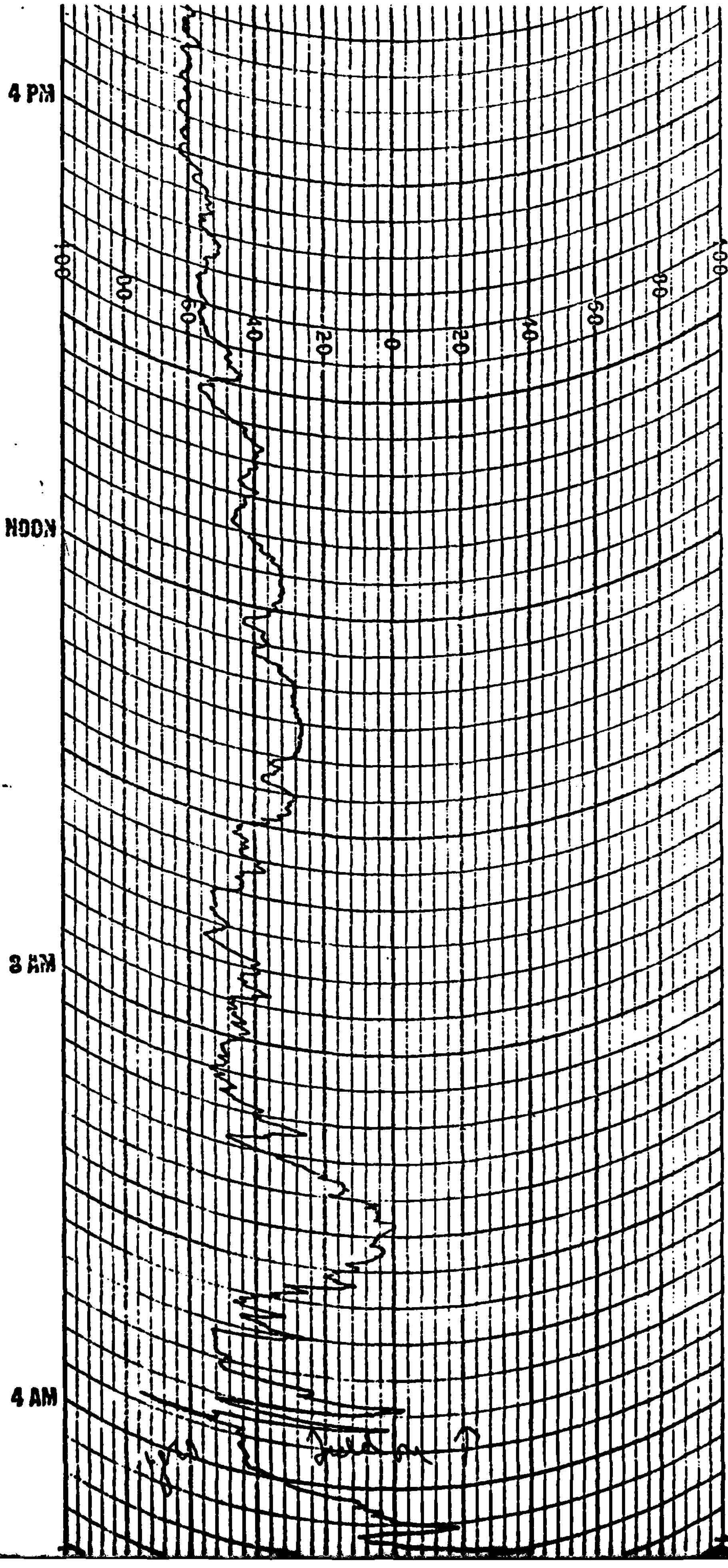



FIGURE 2

Transmitted Light Versus Time

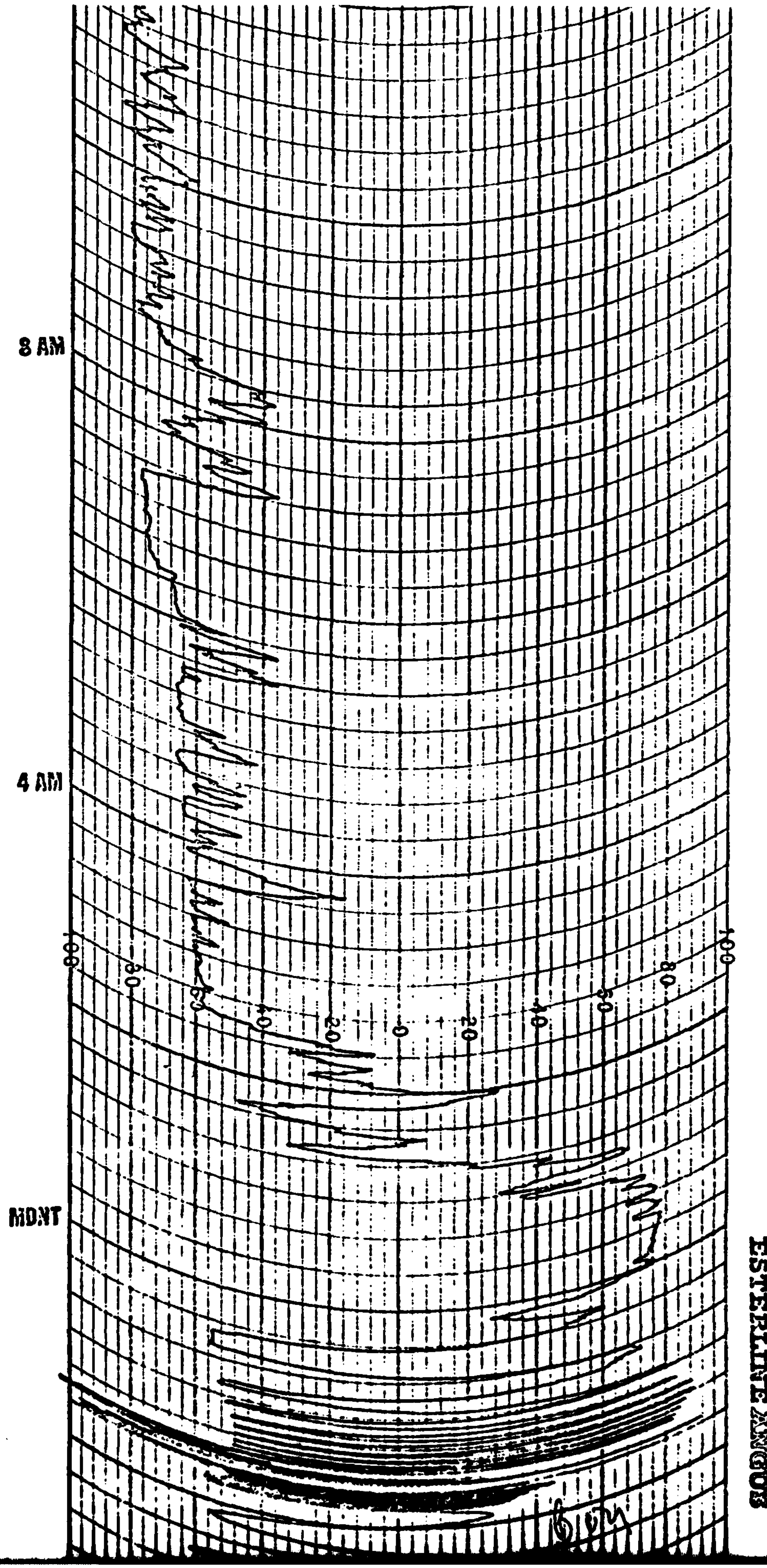



FIGURE 3

Transmitted Light Versus Time

## Conclusion

The interaction of a beam of particles with an ensemble of N particles has been considered. The strength of the interaction, as measured by the transition probability or total cross section, may be enormously increased, if the ensemble consists of particles which are localized and tightly bound. Preliminary experiments appear to verify the theory.

LME

-83